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# INVESTIGATION OF PROTON FLUX IN THE 1.5 - 50 MeV RANGE ON ROBOT SPACE STATIONS "ZOND-4" AND "ZOND-5"

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# INVESTIGATION OF PROTON FLUX IN THE 1.5 - 50 MeV RANGE ON AUTOMATIC INTERPLANETARY STATIONS "ZOND-4" AND "ZOND-5"

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ABSTRACT. Proton fluxes in the 1.5 - 50 MeV range were studied on "Zond-4" and "Zond-5". The apparatus used for this is described, and the results obtained are discussed.

Investigations of the interplanetary atmosphere, carried out in the past few years, have clearly revealed one of its characteristic features — the huge role of the nonstationary processes in the interplanetary atmosphere. It has become clear that for a complete concept of the structure of the interplanetary atmosphere we must have both simultaneous measurements in various regions (which permits determining the spatial characteristics of the atmosphere, including the gradient of the cosmic rays) and measurements carried out in various periods of solar activity. These measurements indicate the time characteristics of the atmosphere and their relationship to solar activity. Of special interest are investigations of the proton fluxes with energies in the range of approximately 0.5 - 10 MeV which is intermediate between the energy of solar wind protons and the protons of cosmic radiation. Investigation of such protons in interplanetary space permitted studying the long-lived solar corpuscular fluxes and the fine structure of the interplanetary magnetic field. /2250*

*Numbers in the margin indicate pagination in the original foreign text.

Most of the published works were performed in the period of minimal solar activity [1 - 3], although reports do exist concerning later investigations [4].

Investigations were carried out on proton fluxes in the 1.5 - 50 MeV range on the automatic interplanetary stations (AIS) "Zond-4" and "Zond-5", launched toward the Moon, respectively, on March 2 and September 15, 1968. Below we give a brief description of the apparatus used for this, and a discussion of the obtained results.

The apparatus for measuring the proton fluxes consisted of two instruments. The first of these (the PRP-1, a semiconductor proton recorder) was a sandwich of two silicon lithium-drift detectors; the second of these detectors (D2) was connected in anticoincidence with the first (D1). The D1 was 1.5 $cm^2$ in area; the D2 — 2.5 $cm^2$. The detectors were shielded from light by an aluminum foil 10 μm thick. The geometric factor $\Gamma$ of the instrument is equal to 3.9 $cm^2 \cdot$ster. The instrument registered protons incident on the D1 with energies of 1.5 - 10 MeV and 10 - 21 MeV.

The second instrument (the PRP-2) was a telescope of two identical silicon lithium-drift detectors D3 and D4 having an area of 2.5 $cm^2$ each. The angle at the apex of the receiving cone was equal to 100°; the distance between the detectors was equal to 14 mm. The instrument was adjusted to register protons in the energy range of 30 - 35 MeV and 45 - 50 MeV by the proper choice of thickness and shape of the absorbers located along the edges and in the center of the telescope, and also by adjustment of the discriminator thresholds. It is important to note that no particles, other than protons, were recorded by this instrument.

## Discussion of Results Obtained

The apparatus for measuring proton fluxes was set up in such a way that, /2251
when the AIS rotated, the instruments carried out the scanning basically in

the plane perpendicular to the plane of the ecliptic. However, in certain segments of the flight trajectory the object completed various maneuvers with change in orientation, and was sometimes fixed along two axes in space. Below we shall look mainly at the results obtained on the "Zond-5".

Figure 1 shows the initial and final segments of the flight trajectory of the "Zond-5" projected on the plane of the ecliptic in the coordinate system with a Earth - Sun fixed line.

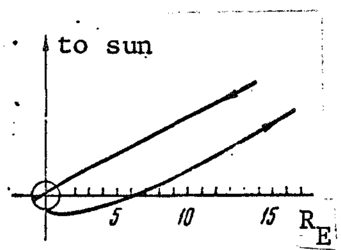


Figure 1. Projection on the plane of the ecliptic of the initial and final segments of the "Zond-5" trajectory.

The initial data were obtained from a distance of approximately 3.5 $R_E$. During this time the AIS intersected the outer radiation belt. In the channel PS-1 (energy range of protons 1.5 - 10 MeV) a high counting rate was noted (apparently due to the electrons), which — in proportion to the distance from Earth — first decreased then again increased, dropping gradually to a level measurable outside the magnetosphere. In the channels PT-1 and PT-2 corresponding to proton measurement with energies of 30 - 35 MeV and 45 - 50 MeV, no increased counting rate was observed with passage through the radiation belt. Short-term "spikes" of the counting rate, lasting sometimes less than a minute, can be traced to the PS-1 channel to a distance of 16 $R_E$.

Here we describe the measurements carried out beginning from the moment corresponding to a distance of 3.5 $R_E$, up to when the apparatus was turned off, carried out on the return path of the AIS at a distance of approximately 14 $R_E$ from the Earth. The data thus obtained clearly characterize the conditions in "free" space between the Earth and the Moon which existed in the period from 15 to 21 September, 1968.

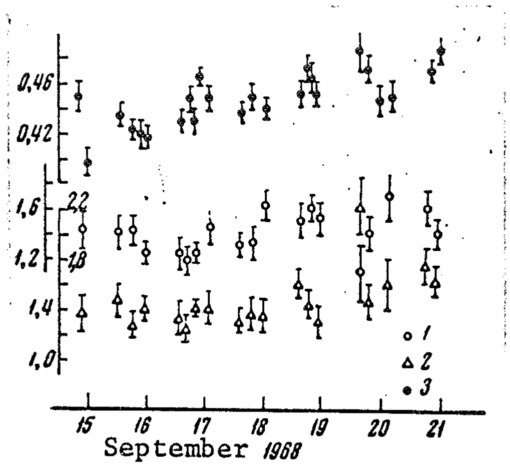


Figure 2. Protons counting rates in the channels: 1 - PT-1, imp·min$^{-1}$; 2 - PT-2, imp·min$^{-1}$; 3 - PS-1, imp·sec$^{-1}$.

Figure 2 shows data on the counting rates in the afore-mentioned channels for the period from 11 hours 16 minutes on September 15 to 13 hours 30 minutes on September 21, 1968. The points on the graph were obtained by averaging over intervals varying from 45 to 140 minutes.

Diurnal averaging makes clearer the slight increase in the counting rate in the PS-1 channel for this period from 0.38 to 0.46 sec$^{-1}$ with a mean square error less than 0.01 sec$^{-1}$. The counting rates in the PT-1 and PT-2 channels also reveal a slight increase. However, on the whole we can state that no substantial variation in the counting rate, which could be attributed to an abrupt change in the conditions in outer space between the Earth and the Moon, was detected on any of our instruments from September 15 to 21. At the same time, the relatively short operation of the apparatus does not permit making any unequivocal conclusion as to whether our instruments measured the background intensity between flares or some relatively /2252 stable level, which significantly exceeds the background. Since the flight of the "Zond-5" took place in a year of maximal solar activity, this latter assumption is more probable. The following correlations were investigated in order to clarify this question.

We analyzed the readings of the neutron monitors at the stations Deep River and Oulu, and the $K_p$-indices of the geomagnetic perturbation [5] for the month of September. They revealed a regular behavior with no abrupt changes which could indicate significant flares of cosmic rays during the period of September 15 - 21, 1968. From the data of optical observations from 1 to 25 September the situation on the Sun was quiet. Only two flares of scale 2 occurred. However, they were not accompanied either by flares of x-rays or by bursts of radio emission in the 3000 MHz range; this indicates that in this case no fast particles were generated. Still another possibility of evaluating the radiation in circumterrestrial outer space in the period of interest to us involved analysis of the data from the SPME instrument on the Earth satellite "Explorer-34". This is a patrol instrument which measures the integral intensities of the proton fluxes in the ranges > 10, > 30 and > 60 MeV. However, the significance of these data for our case was low, since in the channel for protons having an energy > 10 MeV, in order that the counting rate could significantly exceed the average background (caused basically by the energetic particles with energy in the hundreds and thousands of MeV), the intensity of the solar cosmic rays with an energy of tens of MeV would have to increase by 1.5 - 2 orders of magnitude. This may correspond to an increase in the region of 1.5 - 10 MeV by 2.5 - 3 orders of magnitude, in comparison with the "quiet" background in this range [3]. In other words, the fact that during the "Zond-5" flight the SPME instrument did not register (in the channel for protons with an energy > 10 MeV) the amount that the counting rate surpassed the mean level of $0.30 \pm 0.01$ $cm^{-2} \cdot sec^{-1} \cdot ster^{-1}$, indicates only the absence during this period of large flares on the Sun.

Thus, examination of all the above data which characterize the solar and geomagnetic activity for the time, at least, from September 1 to the end of the flight, allows us to make only one conclusion, i.e., that the situation in the circumterrestrial interplanetary space was relatively quiet.

As was mentioned above, the "Zond-5", in accordance with the flight program, sometimes changed orientation and carried out maneuvers in space. The fact that the average intensity of the counting in all channels remained approximately the same, gives us the right to use here such a characteristic as "mean intensity" of the proton flux which is directly associated (through the geometric factor of the instrument) with the mean counting rate. In essence this is equivalent to the assumption of an isotropic character of the proton flux over averaged periods of time.

Allowing for the above, we derive values of the average intensities of the proton fluxes obtained in our experiment:

1.5 - 10 MeV, $I = 0.5 \cdot 10^3$ $m^{-2} \cdot ster^{-1} \cdot sec^{-1}$,
10 - 20 MeV, $I = 40$ $m^{-2} \cdot ster^{-1} \cdot sec^{-1}$,
30 - 35 Mev, $dI/dE = 35$ $m^{-2} \cdot ster^{-1} \cdot sec^{-1} \cdot Mev^{-1}$,
45 - 50 Mev, $dI/dE = 50$ $m^{-2} \cdot ster^{-1} \cdot sec^{-1} \cdot Mev^{-1}$.

The intensities registered by "Zond-4" in March, 1968, agree with these values.

The table gives the values of the "background" intensity of the low-energy proton fluxes obtained on various objects in comparatively quiet (with respect to solar activity) intervals of time for the period from 1964 to /2253
1968. In those cases when the form of the spectrum was known, a conversion was made for the range 1.5 - MeV in order to make a comparison with our data.

VALUES OF BACKGROUND INTENSITY OF PROTON FLUXES IN THE 1 - 10 MeV RANGE

| Object | Period | r, $cm^2 \cdot$, ster | Spectrum in the range 1 - 10 MeV | Flux in the range 1-5 MeV, $m^{-2} \cdot sec^{-1} \cdot ster^{-1}$ | Flux in the range 1.5-10 MeV, $m^{-2} \cdot sec^{-1} \cdot ster^{-1}$ | References |
|---|---|---|---|---|---|---|
| OGO-A | 1964 | 1,51 | $17 \cdot E^{-2,4}$ | 11 | 5,5 | [6] |
| OGO-A | 1965 | 1,51 | $46 \cdot E^{-2,4}$ | 30 | 15 | [6] |
| OGO-3 | 1965 | 1,51 | | 80 | | [6] |
| Venera-2,3 | 1965 | 0,2 | | 7500 [a] | | [7] |
| Zond-3 | 1965 | 0,2 | | 7500 [a] | | [7] |
| | | | | 30 000 [a] | | |
| Mariner-4 | 1964—65 | 0,065 | | 300 [c] | | [2, 8] |
| Pioneer-6,7 | 1966 | 5,8 | $140 \cdot E^{-2,8}$ | 73 | 32 | [3] |
| Venera-4 | 1967 | 0,2 | | 750 [a] | | [9] |
| Mariner-5 | 1967 | 0,116 | $0,7 \cdot e^{\frac{-E}{0,5}}$ | 440 | 165 | [10] |
| Zone-4,5 | 1968 | 3,9 | | | 500 | |
| Venera-5,6 | 1969 | 0,13 | | 770[d] | | [11] |

[a]In Earth orbit (1 a.u.)
[b]In 1.26 a.u.
[c]In Mars orbit (1.55 a.u.)
[d]In range 1 - 4 MeV.

Below we give the brief characteristics used in the operations of the apparatus shown in the table.

The telescope at the University of Chicago installed on the space vehicles of the OGO series consisted of two silicon detectors and a plastic shield. The second silicon detector and shield registered the range of the particle, whereas the first detector measured $\Delta E$. The instrument permitted recording the spectra of the protons and the $\alpha$-particles in the range of 1 - 20 $MeV \cdot nucleon^{-1}$.

Included in the apparatus on board "Mariner-4" and the "Mariner-5" was a surface-barrier silicon detector (Iowa State University) with two thresholds on the first, and four thresholds on the second of these spacecraft. A radioactive source was installed on "Mariner-4" near the detector. The counting rate produced by it was a little higher than the quiet background of the cosmic rays. A correct analysis of the statistical scatter permits determining the upper limit of the fluxes which can not be registered by the instrument in the presence of this radioactive background [8]. The number shown in the table for the "Mariner-4" was obtained on the assumption of a spectrum given in [6]. The radioactive source on the "Mariner-5" was a little weaker, and the background produced by it could be subtracted from the instrument readings. After making certain assumptions, we can determine both the form of the spectrum and the contribution from the $\alpha$-particles.

The telescope from the University of Chicago on the spacecraft "Pioneer-6" and "Pioneer-7" consisted of three silicon detectors in a shield of plastic. The range covered was in the region of low energies - 0.6 - 13 $MeV \cdot nucleon^{-1}$. /2254
On the "Pioneer-7" it was possible to obtain spectra of protons and $\alpha$-particles in this range by using a multi-channel analyzer, turned on by command from Earth.

On the Soviet spacecraft "Venera-2,3,4,5,6" and "Zond-3" there were individual silicon detectors which measured the proton fluxes in the ranges of 1 - 5 MeV and 1 - 4 MeV. The numbers which we show on the table have been obtained on the basis of published counting rates [7, 9] and known geometric factors.

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